PRE-WETTING EFFECT ON FURROW IRRIGATION EROSION: A FIELD STUDY

D. L. Bjorneberg, R. E. Sojka, J. K. Aase

ABSTRACT. *Flowing water quickly saturates dry surface soil as water advances in irrigation furrows. Conversely, rain wets surface soil before runoff occurs. Rapid wetting destroys soil aggregates as water quickly displaces trapped air. Slowly increasing soil water content prior to saturation increases aggregate stability. We hypothesized that instantaneous wetting of dry surface soil during furrow irrigation results in greater soil erosion than if furrow soil was pre-wet immediately before irrigation. We conducted ten irrigation trials on 27-m long furrows in three different fields. Soil was pre-wet by surface drip irrigation (12 to 14 mm) or by lightly spraying with water (1.3 mm). Pre-wetting with drip irrigation significantly ($P < 0.05$) reduced soil loss for 5 of the first 7 irrigations compared to dry soil. The pre-wetting effect on soil loss was not always dramatic, but cumulative soil loss for the first seven irrigations was significantly different among the three treatments: 16, 30, and 56 Mg ha^{-1} for drip, spray, and dry treatments, respectively. The dry treatment never had less soil loss than either pre-wetting treatment. Pre-wetting furrow soil by spraying apparently did not add enough water to stabilize soil aggregates and decrease soil erosion for most irrigations. This study demonstrated that erosion was greater when water flowed over initially dry soil, which is typical with furrow irrigation, compared to water flowing over initially wet soil, which occurs during rain.*

Keywords. *Soil erosion, Furrow irrigation, Aggregate stability.*

Surface irrigation is used on half of the irrigated land in the U.S. (USDA, 1998). Erosion on furrow-irrigated fields greatly reduces crop productivity (Carter et al., 1985) and can seriously impair offsite water quality. Accurate surface irrigation erosion models are needed to estimate sediment reductions from changing irrigation practices or to allocate sediment limits for total maximum daily load (TMDL) standards.

The conditions under which surface irrigation erosion occurs differ from those for rainfall, the conditions which have been the basis for developing most soil erosion simulation models. These systematic differences can cause poor model performance. The WEPP (Water Erosion Prediction Project) model, for example, requires different erodibility parameters for erosion from furrow irrigation than for rain-induced erosion (Bjorneberg et al., 1999). One reason for needing different erodibility parameters may be that rainfall gradually wets the soil before runoff begins. At the onset of rain, droplets wet the soil surface, which consolidates loose soil, and detach soil particles. As runoff begins, rills form in wet soil.

Article was submitted for review in September 2001; approved for publication by the Soil & Water Division of ASAE in January 2002.

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of a product to the exclusion of others that may be suitable.

The authors are **David L. Bjorneberg, ASAE Member Engineer**, Agricultural Engineer; **Robert E. Sojka**, Soil Scientist; and **J. Kristian Aase**, Soil Scientist (retired); USDA-ARS, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho. **Corresponding author:** David L. Bjorneberg, USDA-ARS, Northwest Irrigation and Soils Research Laboratory, 3793 N. 3600 E., Kimberly, ID 83341-5076; phone: 208-423-6521; fax: 208-423-6555; e-mail: bdavid@nwisrl.ars.usda.gov.

For furrow irrigation, rills are mechanically formed in dry soil before irrigation begins. As water advances down the furrow, it flows over dry, loose soil for irrigations following tillage or dry consolidated soil for repeat irrigations. Irrigation water instantaneously wets the soil, rapidly displacing air adsorbed on internal soil particle surfaces (Kemper et al., 1985b). The rapid replacement of air with water can actually break apart soil aggregates (Carter, 1990), likely increasing the erodibility of the soil. Stability of soil aggregates also depends on initial soil water content. Aggregates with greater water content prior to a wet sieving procedure for aggregate stability analysis exhibit greater stability than aggregates with lesser water content (Gollany et al., 1991; Kemper et al., 1985a). Aggregate stability increases when dry soil is humidified to near saturation prior to analysis (Gollany et al., 1991).

Laboratory studies have shown that pre-wetting soil reduces soil erosion. For a simulated rain on 0.37 m^2 trays, pre-wetting the soil reduced runoff and erosion rates compared to air-dried soil (Le Bissonnais and Singer, 1992). Erosion rates for subsequent irrigations continued to be greater from air-dried soil than from pre-wet soil. The pre-wet soil was saturated by capillary action and allowed to drain for about two hours before initiation of simulated rain. A laboratory study with small flumes (0.5 m long) showed that air-dried soil (water content <25 g kg^{-1}) had greater rill erodibility than wet soil (water content >200 g kg^{-1}), and rill erodibility decreased as aging time, which was the time between wetting and testing, increased from 15 min to 4 h to 24 h (Shainberg et al., 1996). The researchers attributed the decrease in erodibility to increased cohesive forces among soil particles. In the field, dry soil beneath wet surface soil causes a large hydraulic gradient that consolidates loose surface soil, which is the phenomena attributed to reducing infiltration during surge irrigation (Kemper et al., 1988). If the soil surface remains saturated during furrow irrigation, then the surface soil does not consolidate. However, a depositional crust can form as water with suspended sediment infiltrates into the soil (Shainberg and Singer, 1985, 1986).

We hypothesized that pre–wet soil would have less sediment detachment and transport in furrow–irrigated fields. Therefore, we conducted a series of studies to determine the significance of the pre–wetting effect on furrow irrigation erosion under field conditions. The purpose of this study was not to develop an erosion control practice, but to demonstrate the effects of a principle that is important to erosion processes in general, and particularly furrow irrigation erosion.

Materials and Methods

We conducted a total of ten irrigations on three different fields (table 1) during 1998, 1999, and 2000 for this study. The first three irrigations were conducted primarily to establish our methods and identify if erosion differences could be measured. The remaining seven irrigations were conducted under slightly different conditions to determine if the pre–wetting effect was consistent on different fields at different times.

Soils in all three fields were Portneuf silt loam (coarse silty mixed superactive mesic durinodic Xeric Haplocalcids), and all fields were located within five kilometers of each other. Field 1 was irrigated grass for pasture or hay from 1991 to 1997, then was plowed in 1998 and left fallow until May 2000, after the last irrigation for this study. Field slope was 1.0% and surface soil (0 to 2 cm depth) organic carbon content was 1.22%. Field 2 was fallow in 1998 and 1999. It had been managed as non–irrigated farmland for at least 10 years prior to this study. Field slope was 1.3% and soil organic carbon was 0.78%. Field 3 had been continuously cropped. The most recent crops were corn (1996–1997), spring wheat (1998), and dry beans (1999). This field was tilled with a field cultivator after bean harvest and before the irrigation experiment. Field slope was 1.2% and soil organic carbon was 0.85%. All irrigations were conducted when no crops were growing.

A 27 m length of furrow was monitored for each irrigation. Inflow rates were chosen so that this furrow length represented the upper quarter of the field (table 2). Thus, sediment detachment and transport by furrow flow were the main erosion mechanisms (Trout, 1996); little if any sediment deposition occurred in these short furrow segments.

Table 1. Experimental field characteristics.

Field	Field Slope (%)	Organic Carbon (%)	Silt (%)	Clay (%)	Cropping History
1	1.0	1.22	58	24	Grass from 1991–1997; fallow in 1998–2000
2	1.3	0.78	58	27	Dryland cropping and fallow from 1985
3	1.2	0.85	60	24	Small grain in 1998; dry bean in 1999

Table 2. Information for each irrigation experiment.

Irrigation	Date	Field	Mean Inflow Rate (L min^{-1})	Reps	Pre–Wetting Water Type[a]
1	8 Sept 98	1	28	4	Tap
2	9 Sept 98	1	28	4	Tap
3	10 Sept 98	1	28	4	Tap
4	29 July 99	2	19	4	Tap
5	3 Aug 99	1	28	4	Tap
6	23 Sept 99	3	15	4	Tap
7	30 Sept 99	3	26	4	Tap
8	26 Apr 00	1	28	2	Tap and RO
9	27 Apr 00	1	21	2	Tap and RO
10	27 Apr 00	1	20	2	Tap and RO

[a] Tap = tap water; RO = reverse osmosis water.

Soil was lightly tilled with a roller harrow or cultivator before irrigation furrows were formed less than 3 days prior to each irrigation. For irrigations conducted on consecutive days in the same field (table 2), each successive irrigation was conducted on a different area of the field so a furrow segment was not irrigated more than once. Prior to irrigating or pre–wetting, surface soil from each furrow was sampled (0 to 2 cm depth) for wet aggregate stability analysis for all irrigations but the first three. Samples were sealed in plastic bags and refrigerated prior to aggregate stability analysis according to the procedure described by Kemper and Rosenau (1986) as modified by Lehrsch et al. (1991). This procedure measures the stability of 1 to 2 mm aggregates.

Pre–wetting treatments consisted of no pre–wetting (dry), pre–wetting by drip irrigation (drip), and pre–wetting by light spraying (spray). Commercially available drip tape with 20 cm emitter spacing was used to slowly wet the furrow soil. One drip tape was run along each side of the furrow (20 to 25 cm apart). Each drip tape applied water at 8.3 L min^{-1} per 100 m of length. Furrows were drip irrigated until the soil in the furrow bottom was wet via capillary flow (90 to 120 min). The two drip tapes on each furrow applied 12 to 14 mm of water and wet an area about 0.3 m wide by 27 m long. Drip irrigation was stopped 30 to 45 minutes before the irrigation started.

Spray pre–wetting took place during the 20 to 30 minutes immediately prior to irrigation. A modified hand–powered plot sprayer with three spray nozzles (Teejet 6504) mounted on a 1–m long boom, parallel to the direction of travel, was used to lightly spray or mist the furrow soil with almost no soil surface disturbance. Each sprayer nozzle applied 1.3 L min^{-1} at 4.3 Pa. By traveling at about 5.5 km h^{-1}, the sprayer applied 0.16 mm per pass. After each furrow was sprayed six times, surface soil samples (0 to 2 cm depth) were collected from each furrow of all treatments to determine soil water content. Soil surface temperature was also measured with an infrared thermometer at this time. Two additional sprayer passes were then made less than 5 minutes before the irrigation. Mean total water depth applied with the sprayer was 1.3 mm. Mean gravimetric soil surface water content prior to irrigation was 33% for drip, 15% for spray, and 4% for dry. Mean soil surface temperature was 23° C for drip, 25° C for spray, and 35° C for dry (table 3).

Table 3. Average gravimetric soil water content (0 to 2 cm depth) and soil surface temperature immediately prior to irrigation.

	Soil Water Content (%)			Soil Temperature (°C)		
Irrigation	Drip	Spray	Dry	Drip	Spray	Dry
1	29	20	3.5	24	25	35
2	29	16	3.4	23	24	30
3	30	13	4.5	22	28	31
4	30	10	3.1	29	31	44
5	34	11	2.3	26	30	43
6	34	16	3.3	25	27	39
7	37	20	3.4	20	23	34
8	38	18	6.1	24	25	39
9	38	14	4.4	13	15	22
10	35	8	2.4	20	22	37
Average	33	15	3.7	23	25	35

Furrow soil was pre–wet with tap water (pH = 7.2, EC = 0.73 dS m^{-1}, SAR = 1.7) for all irrigations except for irrigations 8, 9, and 10, when pre–wetting treatments included both tap water and reverse osmosis (RO) water. Pre–wetting with RO water was included to determine if water chemistry influenced the pre–wetting effect on soil erosion. The RO water had pH = 5.3 and EC = 0.02 dS m^{-1}. SAR was undefined for RO water because sodium concentration was undetectable.

For all studies, irrigation water from the Twin Falls Canal Company (EC = 0.5 dS m^{-1}, SAR = 0.4 to 0.7, pH = 8.2) was supplied by gated pipe to freshly formed, triangular–shaped furrows. Furrow inflow rates were set by measuring the time to fill a 3.8 L bucket. All furrows had the same inflow rate during an irrigation (± 1 L min^{-1}). Small trapezoidal flumes were installed 27 m downslope from the gated pipe for measuring water flow and collecting sediment samples. Water flow rate was measured at 5, 15, 45, 75, 135, and 260 min after water advanced to the flume. At the same times, one–liter runoff samples were collected from the flume outflow with a sampling scoop and poured into Imhoff cones to determine sediment concentration (Sojka et al., 1992). Flow rate was integrated with time to calculate runoff volume. Sediment concentration was multiplied by runoff volume to calculate sediment mass transported during a time interval. Flow–weighted sediment concentration was calculated by dividing total sediment mass by total runoff volume for an irrigation.

A completely randomized block experimental design was used for each irrigation. Irrigations 1 to 7 had three treatments (dry, spray, drip) and four blocks (12 furrows). Irrigations 8 to 10 had five treatments (dry, spray tap water, spray RO water, drip tap water, and drip RO water) and two blocks (10 furrows). Analysis of variance was conducted for each irrigation for total soil loss, total runoff volume, and flow–weighted sediment concentration. Total soil loss, total runoff volume, and overall average flow–weighted sediment concentration for irrigations 1–7 and 8–10 were also analyzed as a split–plot with repeated observations as sub–plots (Little and Hills, 1978) to provide an overall analysis of variance. Soil loss and sediment concentration data for irrigations 1–7 were square root transformed because data were not normally distributed and variances were not homogeneous. Statistical differences were identified using least significant differences (P = 0.05).

Results

Pre–wetting the soil by drip irrigation significantly reduced soil loss during furrow irrigation for five of the first seven irrigations (table 4). Soil loss was not significantly different among treatments for irrigation 3 (P = 0.11), probably because a light, predawn rain (1.8 mm) pre–wet all furrows, reducing the possibility of measuring a pre–wetting effect. Lack of significant difference in soil loss between dry and drip treatments during irrigation 6 likely resulted from the low inflow rate causing little erosion (table 3). The median sediment concentration measured during irrigation 6 was 0.1 mL L^{-1} (90 mg L^{-1}), which is the lowest measurable concentration in the Imhoff cone. In other words, half of the measurements were at or below a detectable concentration. Using a greater flow rate on the same field one week later (irrigation 7) resulted in significant differences between dry and drip treatments (table 4). The 15 L min^{-1} inflow rate was chosen for irrigation 6 because it was the same as the inflow rate used for the last irrigation of the growing season two months earlier (5 Aug 99).

The overall statistical analysis showed that both pre–wetting treatments reduced soil loss for the first seven irrigations. Cumulative soil loss from the drip treatment was 46% less than from the spray treatment, and the cumulative soil loss from the spray treatment was 46% less than from the dry treatment (table 4).

Statistical analysis of flow–weighted sediment concentration showed similar trends as soil loss (table 5). Pre–wetting with drip irrigation significantly decreased sediment concentrations compared to dry soil for every irrigation except irrigation 6 (table 5). Again, sediment concentrations from all treatments during irrigation 6 were low and often undetectable due to the low inflow rate.

Runoff volume was not significantly different among treatments for any irrigation (table 6), indicating that pre–wetting did not have a measurable effect on infiltration in these short furrow segments. Our flow measurement techniques (bucket and stopwatch for inflow rate and flumes for runoff rate) were not always precise enough to accurately calculate the small percentage of water that infiltrated for each irrigation. Only 10% to 30% of the total inflow volume infiltrated during an irrigation; except during irrigation 6 when the inflow rate was low, about 30% to 40% of the inflow infiltrated.

Soil loss and sediment concentration during irrigations 8, 9, and 10 were not significantly different among treatments

Table 4. Total soil loss for irrigations when furrow soil was pre–wet with tap water.

	Soil Loss (Mg ha^{-1})			
Irrigation	Drip	Spray	Dry	Probability
1	1.0 a	3.4 b	16.2 c	<0.01
2	0.5 a	3.0 b	9.5 c	<0.01
3	0.1 a	0.9 a	3.5 a	0.11
4	10. a	12. ab	16. b	0.05
5	0.1 a	1.9 b	2.9 b	0.03
6	0.03 a	0.17 b	0.13 ab	0.04
7	4.6 a	9.0 b	7.5 b	0.02
Total	16. a	30. b	56. c	0.02

Values within a row with different letters are significantly different based on LSD with P = 0.05.

Table 5. Average flow-weighted sediment concentration in runoff from irrigations when furrow soil was pre-wet with tap water.

Irrigation	Sediment Concentration (g L^{-1}) Drip	Spray	Dry	Probability
1	0.5 a	1.7 b	8.5 c	<0.01
2	0.1 a	1.0 b	3.0 c	<0.01
3	0.04 a	0.3 a	1.1 a	0.12
4	6.7 a	7.7 a	9.9 b	0.02
5	0.1 a	0.9 b	1.4 b	0.02
6	0.05 a	0.2 b	0.1 ab	0.04
7	1.8 a	3.8 b	3.1 b	0.02
Average	9.2 a	16. b	27. c	<0.01

Values within a row with different letters are significantly different based on LSD with P = 0.05.

Table 6. Total runoff volume for irrigations when furrow soil was pre-wet with tap water.

Irrigation	Runoff (L) Drip	Spray	Dry	Probability
1	6280	6000	5590	0.06
2	9300	8940	9420	0.22
3	9270	9270	9640	0.81
4	4420	4530	4740	0.37
5	5080	5240	5650	0.72
6	2390	2780	2700	0.07
7	8080	7330	7190	0.28
Total	44800	44100	44900	0.70

(table 7). This surprised us, given that irrigations 1, 2, 3, and 5 were conducted on the same field and had significant soil loss differences among treatments. One possible reason for the lack of differences was that aggregate stability had decreased from 98% stable aggregates for irrigation 5 to 86%, 88%, and 95% for irrigations 8, 9, and 10, respectively. The amount of 1 to 2 mm aggregates was 17% for all four irrigations. Note that the probability of significant differences in soil loss was 0.08% for irrigation 10 where aggregate stability was 95% (table 7). Irrigation 10 was conducted on a portion of field 1 that was chemically fallowed, using herbicide instead of tillage, in 1998 and not tilled until spring 1999.

Table 7. Total soil loss, total runoff and average flow-weighted sediment concentration for irrigations 8–10 when furrow soil was pre-wet with tap water or reverse osmosis (RO) water.

Irrigation	Drip RO	Drip Tap	Spray RO	Spray Tap	Dry	Probability
Soil Loss (Mg ha^{-1})						
8	6.6 a	8.3 a	7.9 a	12. a	8.6 a	0.39
9	2.8 a	2.6 a	3.2 a	2.9 a	3.2 a	0.99
10	0.76 a	0.53 a	2.4 a	2.4 a	2.8 a	0.08
Total	10. a	11. a	14. a	18. a	15. a	0.41
Runoff (L)						
8	8300 a	7890 a	7740 a	7600 a	8010 a	0.08
9	6530 a	6030 a	5260 a	5410 a	5980 a	0.32
10	4480 ab	4090 b	4320 b	4120 b	5010 a	0.04
Total	19300 a	18000 b	17300 c	17100 c	19000 a	0.02
Sediment Concentration (g L^{-1})						
8	2.4 a	3.2 a	3.1 a	4.9 a	3.2 a	0.35
9	1.3 a	1.3 a	1.9 a	1.7 a	1.6 a	0.95
10	0.5 a	0.4 a	1.8 a	1.8 a	1.7 a	0.14
Average	1.4 a	1.6 a	2.3 a	2.8 a	2.2 a	0.24

Values within a row with different letters are significantly different based on LSD with P = 0.05.

Irrigations 8, 9, and 10 also were not as statistically rigorous as previous irrigations because each block only had two replications compared to four replications for the previous tests. The number of replications was limited by our ability to pre-wet the soil with one sprayer. We could only pre-wet four furrows before an irrigation without the soil surface completely drying before starting inflow in the furrows.

Runoff volume was significantly greater for the dry treatment during irrigation 10 (table 7). This difference can probably be attributed more to slightly greater inflow rate than to infiltration differences among treatments, since runoff was not significantly different between any treatments for any other irrigation.

Paired T-tests showed that soil loss was not significantly different between furrows pre-wet with RO water or tap water by spraying (P = 0.29) or by drip irrigation (P = 0.72). Similarly, flow-weighted sediment concentration was not affected by water type for spray (P = 0.43) or drip (P = 0.64) treatments.

Multiple linear regression analysis was conducted with soil loss as the dependent variable and soil water content, soil temperature, aggregate stability, inflow rate, field slope, and soil organic carbon as independent variables. Soil water content, inflow rate, and field slope were the only significant variables for irrigations 1–10, with R^2 = 0.29. Aggregate stability was also a significant variable for irrigations 4–10, with R^2 = 0.46 (aggregate stability was not measured for irrigations 1–3). These analyses showed that soil erosion increased as inflow rate and field slope increased and as soil water content and aggregate stability decreased.

Discussion

The primary difference among treatments was surface soil water content prior to irrigation, although soil surface temperature was also different (table 3). Pre-wetting with drip irrigation increased surface soil water about 8 to 10 times and decreased surface temperature 30% to 40% compared to the dry treatment. When water advanced down the furrow, surface soil was quickly wet to near saturation. The instantaneous increase in surface soil water content was much greater for the dry treatment than either pre-wetting treatment (saturated gravimetric water content is about 36% for Portneuf soil). Slowly wetting soil increases aggregate stability (Gollany et al., 1991), and erodibility decreases with aging time after wetting (Shainberg et al., 1996).

The soil appeared to be better aggregated for irrigations 1–3 than for any other irrigation. This field was tilled (four months before irrigation) for the first time since grass was seeded seven years earlier. Unfortunately, aggregate stability data were not collected before these three initial irrigations. The aggregate stability was likely greater for irrigations 1–3 than for irrigation 5 the following year, after the field was tilled and fallowed for yet another year. The amount of water-stable aggregates tends to decrease with time after grassland is tilled (Low, 1972), and freeze-thaw cycles should not increase the aggregate stability of Portneuf silt loam (Lehrsch et al., 1991). In fact, aggregate stability of Portneuf silt loam tends to increase during the growing season and decreases when frozen (Bullock et al., 1988).

The soil was dry and powdery before irrigation 4 on field 2. The average aggregate stability was 92% for irrigation 4, but only 11% of the sampled soil was in the measured size class of 1 to 2 mm. More than half of the soil (56%) passed through the 1 mm sieve during aggregate stability analysis. Aggregate stability for irrigation 5 on field 1 was 98% with only 17% of the aggregates in the 1 to 2 mm size. Similar soil conditions occurred on field 3 for irrigations 6 and 7. Only 15% of the sampled soil aggregates were in the 1 to 2 mm size class, but these aggregates were very stable (95%). Sixty–five percent of the aggregates were smaller than 1 mm.

The greatest differences in soil loss among treatments occurred during irrigations 1 and 2 on field 1, where each pre–wetting treatment reduced soil loss by about 50% (table 4). These were the only two irrigations when the spray treatment had significantly less soil loss than the dry treatment. The soil in field 1 contained more organic carbon than the other two fields (table 1). We assume that there were more aggregates to be stabilized by pre–wetting on the recently tilled sod in September 1998 than on this same field after being fallowed for a year (irrigation 5) or on fields 2 (irrigation 4) and 3 (irrigations 6 and 7), which had been fallowed and continuous cropped, respectively. Shainberg et al. (1996) also noted that the rate of cohesive force development seemed to depend on a critical water content, which varied by soil type. The soil water content for the spray treatment, which wet the soil much less than the drip treatment (table 3), may not have exceeded this critical water content, and thus cohesive forces among soil particles were not strong enough to reduce sediment detachment.

Relative differences in soil surface temperature among treatments did not help explain differences, or lack of differences, in soil loss. The difference in soil temperature was similar or greater between the dry and spray treatments for irrigations 5–7, when soil loss was not significantly different, and irrigations 1–2, when loss was significantly different between these two treatments.

Erodibility parameters, such as critical shear and rill erodibility used by the WEPP model (Elliot and Laflen, 1993), could not be defined with this data set for each pre–wetting treatment because the range of inflow rates, and thus hydraulic shear, was small. The fact that pre–wetting furrow soil significantly reduced soil loss indicates that separate erosion simulation parameters or procedures should be used for furrow irrigation, where water flows on dry soil, and rainfall, where soil is pre–wet before runoff begins. Although this study was conducted on a Portneuf silt loam, the concept of stabilizing soil by pre–wetting should apply to other soils because aggregate stability changes in Portneuf silt loam are similar to changes in other low organic matter soils from the Northern Plains and Pacific Northwest (Bullock et al., 1988; Lehrsch et al., 1991).

Conclusions

Rapid wetting of dry soil during furrow irrigation caused greater soil loss compared to furrows that had been pre–wet by drip irrigation. The effect was greater where the soil had greater organic matter content and greater amount of stable aggregates. The pre–wetting effect on soil loss was not always dramatic, but it was significant for five of seven irrigations on three different fields with the same silt loam soil. The dry treatment never had significantly less soil loss than the drip treatment. Pre–wetting furrow soil by spraying did not add enough water to stabilize soil aggregates and decrease soil erosion for most irrigations. The fact that pre–wetting furrow soil significantly reduced soil loss indicates that separate erosion simulation parameters or procedures should be used for furrow irrigation, where water flows on initially dry soil, and rainfall, where soil is pre–wet before runoff begins.

References

Bullock, M. S., W. D. Kemper, and S. D. Nelson. 1988. Soil cohesion as affected by freezing, water content, time, and tillage. *Soil Sci. Soc. Am. J.* 52(3): 770–776.

Bjorneberg, D. L., T. J. Trout, R. E. Sojka, and J. K. Aase. 1999. Evaluating WEPP–predicted infiltration, runoff, and soil erosion for furrow irrigation. *Trans. ASAE* 42(6): 1733–1741.

Carter, D. L. 1990. Soil erosion on irrigated lands. In *Irrigation of Agricultural Crops*, 1143–1171. B. A. Stewart and D. R. Nielson, eds. Agronomy Monograph No. 30. Madison, Wisc.: ASA.

Carter, D. L., R. D. Berg, and B. J. Sanders. 1985. The effect of furrow irrigation erosion on crop productivity. *Soil Sci. Soc. Am. J.* 49(1): 207–211.

Elliot, W. J., and J. M. Laflen. 1993. A process–based rill erosion model. *Trans. ASAE* 36(1): 65–72.

Gollany, H. T., T. E. Schumacher, P. D. Evenson, M. J. Lindstrom, and G. D. Lemme. 1991. Aggregate stability of an eroded and desurfaced typic argiustoll. *Soil Sci. Soc. Am. J.* 55(3): 811–816.

Kemper, W. D., and R. C. Rosenau. 1986. Aggregate stability and size distribution. In *Methods of Soil Analysis: Physical and Mineralogical Methods*, Part 1: 425–442. 2nd ed. A. Klute, ed. Madison, Wisc.: ASA.

Kemper, W. D., R. C. Rosenau, and S. Nelson. 1985a. Gas displacement and aggregate stability of soils. *Soil Sci. Soc. Am. J.* 49(1): 25–28.

Kemper, W. D., T. J. Trout, M. J. Brown, and R. C. Rosenau. 1985b. Furrow erosion and water and soil management. *Trans. ASAE* 28(5): 1564–1572.

Kemper, W. D., T. J. Trout, A. S. Humpherys, and M. S. Bullock. 1988. Mechanisms by which surge irrigation reduces furrow infiltration rates in a silty loam soil. *Trans. ASAE* 31(3): 821–829.

Le Bissonnais, Y. L., and M. J. Singer. 1992. Crusting, runoff, and erosion response to soil water content and successive rainfalls. *Soil Sci. Soc. Am. J.* 56(6): 1898–1903.

Lehrsch, G. A., R. E. Sojka, D. L. Carter, and P. M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. *Soil Sci. Soc. Am. J.* 55(5): 1401–1406.

Little, T. M., and F. J. Hills. 1978. *Agricultural Experimentation: Design and Analysis*. New York, N.Y.: John Wiley and Sons.

Low, A. J. 1972. The effect of cultivation on the structure and other physical characteristics of grassland and arable soils. *J. Soil Sci.* 23(4): 363–380.

Shainberg, I., and M. J. Singer. 1985. Effect of electrolytic concentration on the hydraulic properties of depositional crust. *Soil Sci. Soc. Am. J.* 49(5): 1260–1263.

______. 1986. Suspension concentration effects on depositional crusts and soil hydraulic conductivity. *Soil Sci. Soc. Am. J.* 50(6): 1537–1540.

Shainberg, I., D. Goldstein, and G. J. Levy. 1996. Rill erosion dependence on soil water content, aging, and temperature. *Soil Sci. Soc. Am. J.* 60(3): 916–922.

Sojka, R. E., D. L. Carter, and M. J. Brown. 1992. Imhoff cone determination of sediment in irrigation runoff. *Soil Sci. Soc. Am. J.* 56(3): 884–890.

Trout, T. J. 1996. Furrow irrigation erosion and sedimentation: On–field distribution. *Trans ASAE* 39(5): 1717–1723.

USDA. 1998. Farm and ranch irrigation survey. National Agricultural Statistics Service. Available at: www.nass.usda.gov/census/. Accessed Sept. 2000.